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ORIGINAL ARTICLE

A generalized mathematical model to determine the turning movement counts at roundabouts

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Abstract Traffic turning movement counts at roundabouts is one of the key inputs required for roundabout assessment, control and management. Traditionally, a direct counting is conducted to track a vehicle from entering through circulation until exiting. This counting may be difficult and costly due to the size of roundabout, the vision obstacles, and the continuous traffic flow. Many researchers tried to avoid the tracking problem by counting only at entries and exits, then estimating the movements based on historical data which unfortunately affect the results. Other researchers reduced the tracking problem by counting some turning movements in addition to at entries and exits, then calculating mathematically the remaining movements. This approach is practical and accurate; however, it was applied on limited cases. In this paper, a generalized mathematical model was developed to calculate the most difficult movements based on the easiest movements determined based on the size of monitoring area. The developed model can be used to calculate the turning movements, including the u-turns, for roundabouts with any number of legs. The developed model was presented in O–D matrix forms to be practical and user-friendly. The model was validated against reference count data and the results were found to be satisfactory.

1. Introduction

Roundabouts are one of the widely used types of intersections nowadays. They serve a major role in regulating vehicle turning movements from one direction to another in a safe and efficient manner. Determination of traffic turning movement counts at roundabouts is one of the key inputs required for a variety of traffic analysis, including intersection geometric design, traffic control devices design, traffic impact assessment, capacity estimation, safety evaluation, etc. Standard intersections are relatively straightforward to count, but for roundabouts the situation is different [1]. It may be difficult and costly to track a vehicle from entry through circulation until exit the roundabout due to the size of roundabout and the vision obstacles. Additionally, the continuous entry of new vehicles from all legs makes it difficult to track every vehicle. For these reasons, the traditional and direct counting survey conducted by manual manner, counters, or even video cameras may not necessarily

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be appropriate as a workable methods especially for large roundabouts and roundabouts with site limitations.

Estimating turning movement volumes at roundabouts, given some level of field measurements as input, is an alternative to full and direct field observations. Based on this approach, several attempts to estimate turning movement volumes were developed making the use of traffic counts only at entries and exits and historical data for turning movement volumes [2–10]. Unfortunately, the results obtained by such methods may be inaccurate due to the influence of the used seed data.

Another approach was developed to reduce the tracking problem by counting some turning movements in addition to in-flows and out-flows. Then, it could be possible to calculate the remaining turning movement volumes using mathematical models [11,12]. Although this approach is practical and accurate; the developed models, based on this approach, have many potential shortcomings, as follow. No general models were developed to estimate turning movement volumes for roundabouts with any number of legs. The developed models were based on the assumption that no U-turn movements from and to the same roundabout leg are available. Moreover, the important topic of economizing and simplifying field data collection was not addressed in this approach.

The purpose of this paper is to develop a generalized mathematical model to overcome the above mentioned shortcomings. More specifically this paper aims to:

- Calculate the most difficult turning movements based on counting only out-flows, circulating flows in addition to the easiest turning movements.
- Include the u-turn movements in the calculations, for roundabouts with any number of entries and exits.
- Reduce the number of the detectors or counters in addition to simplify the setting up.
- Present the developed model in an O–D matrix form to be practical and to easily calculate the turning movements for any roundabouts.

The paper is divided into four sections. Following the introduction is a proposed approach of the developed methodology including basic definitions, monitoring area, and equations system. Then, the model development section is presented. Next is a validation of the developed method based on real observation data. Finally, a summary of main conclusions and suggestions for future work is given.

2. Proposed approach

The proposed approach aims at calculating mathematically the most difficult turning movements, based on out-flows, circulating flows, and the easiest turning movements in the roundabout. The criterion used to decide whether the movement is easy or difficult is the size of the area to be monitored to track any vehicle. The following subsections discuss the concept of monitoring area size, equations system and the basic definitions used to develop the proposed model.

2.1. Basic definitions

In this subsection, the used terms in developing the proposed model will be defined.

Out-flow O_i: Total traffic flow leaves leg i (e.g. O_2 means the traffic flow leaves leg/exit 2).
Circulating flow C_i: Total traffic flow circulates in front of leg i (e.g. C_2 means the traffic flow circulates in front of leg 2).
Turning movement M_i^k: Traffic flow leaves the roundabout at leg i and comes from k legs before leg i (e.g. M_3^1 means the traffic flow leaves from leg/exit 3 and comes from leg/entrance 2).

NB: U-turning movement has $k = 0$, right-turn movement has $k = 1$, and left-turn movement has $k = N - 1$, where N is the number of the roundabout legs.

Succeeding turning movement M_{i+j}^k: Traffic flow leaves the roundabout at leg/exit after i by j legs and comes from the leg/entrance before $i + j$ leg by k legs (e.g. M_{2+1}^0, u-turning flow, the traffic flow leaves the roundabout at leg/exit 3 and comes also from leg/entrance 3, another example M_{2+1}^2 is the traffic flow leaves the roundabout at leg/exit 3 and comes from leg/entrance 1).

NB: if $i + j > N$ then $i + j$ should be considered $i + j - N$ (e.g. in the 3-leg roundabout, M_{3+2}^1 means the traffic flow leaves the roundabout at leg/exit 2 and comes from leg/entrance 1).

2.2. Monitoring area

In any roundabout, both out-flows and circulating flows need the smallest monitoring areas to be tracked. Each right-turn needs a monitoring area covering $\frac{1}{N}$ of the roundabout area, where N is the number of roundabout legs. Also, each through movement needs a monitoring area covering $\frac{1}{2}$ of the roundabout area. For left-turn movements, each one needs a monitoring area covering $\frac{N-1}{N}$ of the roundabout area. For U-turns, each movement needs a monitoring area covering $\frac{N-2}{N}$ of the roundabout area. Therefore, the easiest movements are out-flows and circulating flows while the most difficult movements are the left-turns.

In 3-leg roundabouts, the monitoring area size of right-turn and u-turn may be equal, however, u-turn is easier than right-turn due to the possibility of conflict in the case of right-turns. On the other hand, in 4-leg roundabouts, the monitoring area size of through movement and u-turn may be equal; however, u-turn is easier than through movement due to the possibility of conflict in through movements.

2.3. Equations system

The proposed equations system is a determinant system of linear equations having the two difficult turning movements as unknowns and the easiest turning movements in addition to out-flows and circulating flows as inputs. The number of observations should be equal to the number of unknowns, in the determinate equation system. In the 3-leg roundabouts, the unknowns are left-turning, and right-turning movements while the easiest observations are out-flows, circulating flows, and u-turning movements if exist. Similarly, in the 4-leg roundabouts, the unknowns are left-turning, and through movements while the easiest observations are out-flows,